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Analysis of streams in local systems with distributed generation by methods of graph theory

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Abstract: *Analysis of streams in local systems with distributed generation by methods of graph theory.* The graph theory is a simple and powerful construction tool of models and optimization of analyzed tasks. Now there is a set of problems where it is required to construct difficult complex systems. There are solved in view of the certain ordering of their elements. The choice of optimum routes and streams in electro-generating networks, constructions of independent source of electricity in changing topology networks with distributed generation are concerned.

Key words: electro-generating networks, graph theory, linear programming.

Distributed generation (DG) is an emerging concept in the electricity sector, which represents good alternatives for electricity supply instead of the traditional centralized power generation concept. The electrical grid is one of the largest infrastructures ever built. This infrastructure has been built regarding a generation model where large centrals should provide the electricity to supply all the customers. In this grid topology, the power produced by these centrals is transmitted in HV to consumption points, changing there to MV for its distribution and finally is transformed to LV for its consumption. Due to environmental concerns and the variable price of fossil fuels, renewable energy sources are getting more importance for power generation. Even if large wind farms or hydroelectric centrals are connected to the transmission grid, a large amount of renewable energy is connected to the local network. These generation units can be defined as distributed generation. The increasing penetration of DG is already changing the network topology [1, 2].

The graph theory is a simple and powerful construction tool of models and optimization of analyzed tasks [3, 4]. This theory has simple elements and ideas in the basis: the points connected by lines that allows to build of them rich variety of forms and as a result to become useful means at research of various systems. Now there is a set of problems where it is required to construct difficult complex systems. There are solved in view of the certain ordering of their elements. The choice of optimum routes and streams in electro-generating networks, constructions of independent source of electricity are concerned.

At studying streams it is enough to be limited focused coherent graphs. Such graphs will refer to as networks [3, 5].

In network *N* is a function φ. It has determined on *A*. Integer $\varphi\,(a)$ refers *as a stream on an arch a*. If a $\cong (\upsilon, \omega)$, so the stream is directed from υ to ω at $\varphi(a) \geq 0$ and from ω to υ at $\varphi(a) \leq 0$.

The direction of a stream is defined by familiar $\varphi(a)$.

Tops of network N are usually classified on their influence on a stream φ (create, absorb or keep a stream). To formalize classification, we shall designate through $\upsilon \to V$ set of arches for which υ is initial top, and through $V \to \upsilon$ – set of arches for which υ is final top. Then integer Q (υ, φ) is determined by a correlation:

$$Q(\upsilon, \varphi) = \sum_{\upsilon \to V} \varphi(a) - \sum_{V \to \upsilon} \varphi(a) \qquad (1)$$

It is called to *as a clean stream* from υ be relative φ. If $\varphi(a) \geq 0$ is in each arch, so the first sum is simply general stream following from top υ. The second is the general stream flowing into top υ. If in some arches streams are negative, the allocated sums have no named interpretation. Their difference are still represent a clean stream from top υ.

The tops of network N are grouped in sets V^+, V^- and V^0 as follows:

$$V^+ = \{\upsilon \in V \mid Q(\upsilon) > 0\}$$
$$V^- = \{\upsilon \in V \mid Q(\upsilon) < 0\} \qquad (2)$$
$$V^0 = \{\upsilon \in V \mid Q(\upsilon) = 0\}$$

Elements of sets V^+, V^- and V^0 are called as sources, drains and intermediate tops. These tops accordingly are create, consume and keep a stream.

The network keeps in whole any stream φ such as $\sum_{\upsilon \in V} Q(\upsilon) = 0$

It is easy to see in the following expression:

$$\sum_{\upsilon \in V} Q(\upsilon) = \sum_{\upsilon \in V} \sum_{a \in (\upsilon \to V)} \varphi(a) - \sum_{\upsilon \in V} \sum_{a \in (V \to \upsilon)} \varphi(a) \qquad (3)$$

Each arch of a network enters once into each double sum.

The circuit of autonomous system of power supply is resulted on Figure 1:

υ_1 – the centralized source of electric supply;

υ_2 – the autonomous power station with a drive motor of internal combustion;

υ_3 – the accumulator of energy and the static converter of the electric power;

υ_4 – the electric consumer.

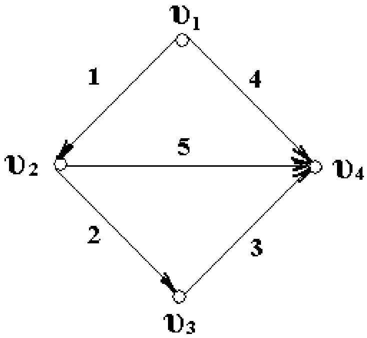

FIGURE 1. The graph of a network

Energy source we shall designate through 1, and a drain through 2. The characteristics of tops and arches the graph are resulted on the Table 1.

If in a network there is only one source υ_i and only one drain υ_j, the stream is

TABLE 1. The table of characteristics of graph tops

	υ_1	υ_2	υ_3	υ_4
1	1	–1	0	0
2	0	1	–1	0
3	0	0	1	–1
4	1	0	0	–1
5	0	1	0	–1

considered from υ_i in υ_j. The size $Q(\upsilon_i)$ or $Q(\upsilon_j)$ is called *as size of a stream*. For convenience the same terminology is distributed in a case of streams of zero size, for which $Q(\upsilon) = 0$ in all tops.

Any stream in the network can be transformed to a stream which has only one source and one drain and increased amount of tops in network. For example, we shall add new top ω_1 and arches $b_i \cong (\omega_1, \upsilon_1)$, leaders from ω_1, to each source of a network. To these arches we shall attribute a stream

$$\varphi(b_i) = Q(\upsilon_i) \tag{4}$$

Similarly, we shall add the second top ω_2 and arches $c_j \cong (\upsilon_j, \omega_2)$, which conduct from each drain to top ω_2 and have a stream

$$\varphi(c_j) = -Q(\upsilon_j) \tag{5}$$

In result we shall receive a network with one source and one drain. We shall consider attitudes between streams. Let φ_1 and φ_2 are streams in same network $N = (V, A)$, and let p is an integer. Then for each arch $a \in A$. The streams $\varphi_1 + \varphi_2$, $\varphi_1 - \varphi_2$ and $p\,\varphi$ are defined with the help of the following parities:

$$\begin{aligned}(\varphi_1 + \varphi_2)(a) &= \varphi_1(a) + \varphi_2(a)\\ (\varphi_1 - \varphi_2)(a) &= \varphi_1(a) - \varphi_2(a)\\ (p\varphi_1)(a) &= p\varphi_1(a)\end{aligned} \tag{6}$$

It is easy to see, that

$$Q(\upsilon, \varphi_1 \pm \varphi_2) = Q(\upsilon, \varphi_1) \pm Q(\upsilon, \varphi_2)$$

$$Q(\upsilon, p\varphi_1) = pQ(\upsilon, \varphi_1)$$

From here follows, that if φ_1 and φ_2 are streams from υ in ω, having sizes k_1 and k_2 accordingly $\varphi_1 + \varphi_2$ also is a stream from υ in ω and has size $_{k1}$ + $_{k2}$. Similarly, $\varphi_1 - \varphi_2$ there is a stream having size $k_1 + k_2$. and directed from υ to ω, if $|k_1 - k_2|$ or from ω to υ, if $k_1 \le k_2$. (The stream of bullets size can be counted as direct from both υ to ω, and from ω to υ.) And at last, the stream $p\varphi$ has size $|pk_1|$ and is directed from υ to ω, if $p \ge 0$, and from ω to υ, if $p \le 0$.

Let's result substantive provisions of linear programming in networks.

Let tops υ_0 and υ_n are focused the graph designate a source and a drain of some substance proceeding on arches. Besides we shall assume, that from top υ_i in top υ_j throughput or the top restriction on size of stream C_{ij} is put to an arch in conformity. At last, let C_{ij} is designated cost of unit of a stream on an arch. Now the task about a stream can be presented as a task of linear programming. It is required to minimize $\sum_{i,j} C_{ij}\chi_{ij}$ for the general stream *with* from υ_0 in υ_n under conditions:

$$\sum_j (\chi_{0j} - \chi_{j0}) = c \tag{7}$$

$$\sum_j (\chi_{ij} - \chi_{ji}) = 0 \text{ for } i = 1, \ldots, n-1$$

$$\sum_j (\chi_{nj} - \chi_{jn}) = -c \tag{8}$$

$0 \le \chi_{ij} \le c_{ij}$ for each arch.

Streams in networks sometimes are appeared convenient means of the decision of a task of linear programming. Such type which is known under the name of a transport task.

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Streszczenie: *Analiza przepływów w systemach lokalnych z rozproszoną generacją przy użyciu metod teorii grafów.* Teoria grafów jest prostym i mocnym narzędziem w konstrukcji modeli i optymalizacji analizowanych zadań. Obecnie występuje wiele problemów wymagających konstruowania trudnych i złożonych systemów. Są one rozwiązywane w celu pewnego uszeregowania ich elementów. Dotyczy to wyboru optymalnych ścieżek i przepływów w sieciach wytwarzania energii elektrycznej, konstrukcjach niezależnych źródeł elektryczności i zmianach sieci topologicznych o rozproszonej generacji.

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